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Enhancement of Performance Parameters Of Transformer Using Nanofluids

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Abstract*— Transformer is a soul of both transmission and distribution systems. It performs low voltage to high voltage conversion in transmission lines and similarly high voltage to low voltage conversion in distribution lines. The operation of transformer is decided by the cooling provided to the system. The efficient cooling method is achieved by the use of forced (or) natural oil cooling medium. The oils used for the purpose of coolants are the hydrocarbons of paraffin (or) naphtha based petroleum products. The oil is used as coolant is made from highly refined mineral oil and it has high dielectric strength. During the operation of transformer there occurs temperature variation in the oil which causes reduction in dielectric strength with emissions of dissolved gases like sulphur, moisture etc. The mineral oil used in existing system is the dominant material in use but thermal conductivity is less. The insulating property of transformer provides poor results by the use of oil cooling medium.So, to achieve the best cooling the researchers introduced nano based oil, called "Nanofluids". A nanofluid has attracted much in the field of research and its wide applications in the field of engineering. It is a mixture of nano-sized solid particles and base fluid. The major role of nanofluids is to improve the electrical, physical and chemical parameters of transformer. There are various varities of nanoparticles which improve the electrical and physical properties of transformer oil; among the various nanoparticles available are alumina particle (Al_2O_3), copper oxide (CuO), titanium oxide (TiO_2) etc. Then its performance is being checked by simulation and experimental data.

Keywords—Nano particles, Nano Fluids, Transformer Oil, Heat transfer

I. Introduction

Transformer is a non-movable machine that transforms power from one circuit (primary) to another circuit (secondary) with constant frequency. The transformer is first commenced in the year 1880 and brings the soul of the power system. The first 400 KV power transformer was introduced in the year 1950 for high voltage purpose. The generation of electrical energy in low voltage level is much economical; hence it is desirable to generate power in LV level. Transformer plays an important role in conversion of voltage levels (LV-HV or HV-LV). [1]

Transformer can be classified in different ways:

- Step up and step down transformer
- Three and single phase transformer
- Power, distributed and instrument transformer
- Two winding and auto transformer
- Outdoor and indoor transformer.

In the last two decades the major issues that are focused are low heat losses (hence higher efficiency), higher service reliability and better insulation.

Thermal effect is the major factor which decides the performance and protection of liquid- immersed transformers. The size of the power transformers used in both generating and distribution networks are larger than 500 kVA. The core of the transformers is laminated by steel with copper or aluminum winding. The windings used in the core have provided a solid insulation of refined paper and the oil acts as insulating and cooling medium. The major parameters in the core, windings, and insulation are hike of temperature in core that is transferred to the cooling agent (oil), heat losses in the winding.

The temperature rise in transformer core also affects the MVA rating of the transformer and it is based on the maximum allowable temperature of the insulation. Transformer can continuously deliver the rated power output at rated voltage and frequency without exceeding the temperature. This temperature rise affects the thermal limitation of core, winding and insulation. As per the international design standards, the temperature limit can rise above measured ambient temperature. The ambient temperature ensures that transformer has sufficient thermal capacity and independent of daily environmental conditions. Fig 1 shows the how the transformer operates and functions its cooling property. [2]

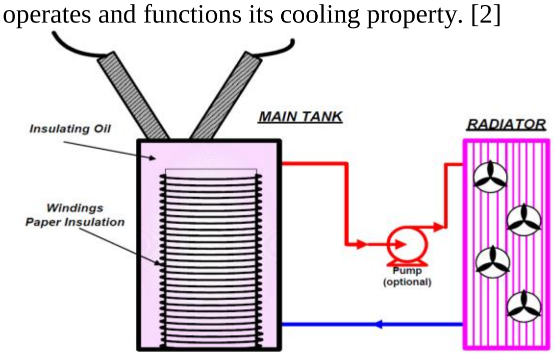

Fig 1: Basic Arrangement of Transformer [3]

The major challenge in the power transformers is to limit the temperature rises to the core materials and thermal capability of the insulation. These temperature rises can cause heat losses in the transformers winding. Based on the voltage and frequency parameters the power output of transformers are rated, without exceeding the specified temperature hike. The temperature rise also affects MVA rating of the transformers and the temperature should not exceed maximum allowable temperature of the insulation.

The significant sources of heating in the windings of transformer are no-load losses and on-load losses. No-load losses are caused by hysteresis and eddy losses in the core of the transformers, and these losses occur when transformers are energized. Hysteresis loss is present due to the contraction in elementary magnets and magnetic material aligning with the alternating magnetic field. Eddy current loss is due to the leakage current flowing into the core winding and by the alternating magnetic field. The quantity of eddy current and hysteresis losses mainly depends upon the exciting voltage of the transformers.

The significant source of on-load losses are losses in copper material due to the winding resistance and stray loss due to eddy currents flows into the windings. The copper loss mainly consist both winding eddy current loss and dc resistance loss. The amount of losses is directly proportional to increase in temperature. With the increase of temperature the dc resistance also increases and the amount of loss is dependent upon transformer load currents. All of these factors are taken into the considerations for the calculation of thermal transformer performance. [3,4]

Operating temperature in the transformers is used to estimate the heating and cooling based on the current measured on one side of the transformer. The maximum temperature is calculated based on the thermal replica model and also to estimate the maximum permissible current in the core.

II. Material and Methodology

Transformer Oil

Transformer is the soul of the power system and its operation on high voltages completely depends upon the cooling provided by the insulating oil.

The recent used insulating oil the bye product of crude oil and produces by the fractional distillation method. Crude oil is the mixture of hydro carbons with various molecular weights. Fractional distillation method undergoes the cycle of conversions like first crude oil is converted to petrol and then it is converted to base oil of desired properties. The insulating oil is highly refined mineral oil that should operates stably at high temperatures and it should be excellent electrical insulating properties. It is used in oil filled transformers and its basic functions are to insulate, suppress and arcing and to serve as coolant. The insulating oil plays a major role to provide the anti aging to transformer, heat transfer capability, efficiency etc. After a deep study it is found that existing system has several important considerations

- Moisture and sulphur content at the variations of temperatures affects the dielectric properties of the oil and affects the transformer ratings.
- Heat is one of the most common problems of transformers. Operation at only 10 degree centigrade above the transformer rating will cut transformer life by 50%. This heat is caused internal losses due to loadings, high ambient temperatures and solar radiations(environmental aspects)
    - Dissolved gases during the running condition of transformers may damage the transformers.

Method of Cooling

The basic idea behind the cooling of transformer is transferring of heat from core and windings to the insulating oil. The methods involves in the cooling are natural circulation and forced air cooling. Natural circulation of cooling, transfers the heat to external radiators and the radiators are used to increase the cooling surface area of the transformer tank. There is an additional arrangement of pumps to increase the flow of oil, hence increasing the efficiency of radiators. There are two types of flow arrangement in transformers non-directed flow and directed flow. The oil is pumped and flows freely through the tank in non-directed flow transformers and if the oil is pumped forcefully to flow through the windings then this type of arrangement is called directed flow transformers. Forced air cooling method is used to apply on large power transformers and it uses fans to blow air over the surface of the radiators and this provides double efficiency to the radiators. It is important to improve the existing oil to provide a better cooling system to enhance the heat transfer capability of transformers.

III. Results and Tables

The introduction of nanofluid provides new area of research in the field of applications in engineering. Nanofluid is the combined form of nanoparticles and base fluid. The nanoparticles are nanosized crystalline type material and it has the size below 100 nm (nano meter). The basic nanoparticles that are used to enhance the performance parameters are Al_2O_3, CuO, TiO_2, Fe_3O_4, carbon nanotubes etc. The presence of nanoparticles into the base fluids increase the surface area of oil, hence this characteristic not only enhances the heat transfer capability but also increase the stability of suspension. Xuan and Li [9] explained that due to its nanostructure characteristic, it provides enhanced properties i.e. thermal, mechanical, physical and chemical than normal oil of transformer. In general, there are four types of nanomaterials: carbon based (carbon nanotubes), metal based (aluminum oxides), dendrimers (nanosized polymers) and composites (nanosized clays). When these nanoparticles are mixed with normal oil (transformer oil (or) other machine oil) called “nanofluids”. A study of Kakac and Pramuanjaroenkij [12] concluded that nanolayer in nanofluids makes a thermal bridge between base fluid and solid nanoparticles. After clear studies it is found that it improves thermo-physical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficient. These properties depend on the volumetric fraction of nanoparticles, shape and size of nonmaterials as shown by Yang et al. [10]. Due to its characteristic properties, it has a wide range of applications in the field of engineering like automotive and cooling of transformer, air conditioning, improving diesel generator efficiency, nuclear reactor, solar and power plant, defense and space, referred by Xiang and Arun [11]. Nanofluids have several applications in engineering field

- The mixed nanoparticles enhance the thermal conductivity which results improvement in efficiency of heat transfer system.
- Solar energy absorption will be based on the size, shape, material and volumetric concentration of nanoparticles.
- Nanofluids as a coolant, allow better positioning and smaller size of the cooling system. The paper presented by Saidur et al., [12] showed that use of nanofluid coolant in radiators can reduce the front area of the radiator up to 10% and can save fuel by 5%.

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- To make better for various applications, properties of fluid can be changed by varying the concentration of nanoparticles into normal base fluids.

Equipments Required:

1. Redwood Viscometer

- The set up will be required two type of oil, one is normal mineral oil and other nanobased oil and then the electrical properties and thermal properties will need to observe with the help NIST-SUPERTRAPP software.
- Using Redwood Viscometer the property of viscosity of different type of oil with and without nanoparticles will be observed.
- The various nanoparticles (Al_2O_3, MgO, ZnO etc) will be suspended into the different base oils and thermal conductivity and viscosity data will be observed using graphical data.
- Using dielectric setup the dielectric strength of oil with and without nanoparticles will be practiced and observation based on the changes in oil after addition of nanoparticles will be viewed.
- Practical approach will be done on the basis of two electrodes method in which one will be inserted in normal oil and other in nanofluid based oil.

The experimental work on viscosity of oil using Redwood viscometer and observed different changes in flow of oil at various temperatures.

S.No	Temperature (^{0}C)	Time (seconds)	Viscosity (Pascal-sec)
1	28	401	1.038311
2	33	308	0.795216
3	38	265	0.682509
4	43	219	0.561546
5	48	180	0.458444
6	53	133	0.332868
7	58	110	0.270364
8	63	99	0.240026
9	68	60	0.127333
10	73	59	0.124247
11	78	56	0.114886
12	83	50	0.0956

Table 1: Tabular column of experiment for viscosity of normal base oil

The above experimental data is based on the castor oil (lubrication oil) and I have observed that as temperature increases the time of flow of oil increases. Using the above observational data the viscosity of oil will be calculated using given formula.

Formula: Viscosity i.e. r = (At^2-B)/t, where, A and B are constant values and t is the time in seconds. The values of A and B are, 0.0026 and 1.732.

Viscosity Calculation:

1. At time = 401 sec, r = (0.0026*(401)^2-1.732)/401=1.038311 (Pascal-sec)
2. Thermometers
3. Temperature regulator
4. Flask
5. Stop watch

- Normal oil (castor, naphtha (or) paraffin based)

Respectively values of viscosities at different time were calculated above shown in table 10.1

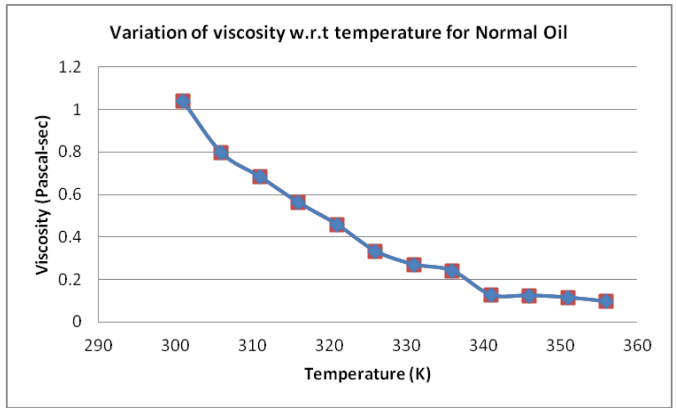

Fig 2: Viscosity vs. Temperature curve for normal base oil

The fig 2 shows the variation of viscosity with respect to temperature for normal base oil. As per the graphical data shown it is observed that for normal base oil the viscous property starts loosing at higher temperature. For any transformer oil it is desirable to have lower viscosity at higher temperature variations. But for normal base oil the above statement does not follow. Hence researchers found nanoparticle suspension into the common base oil to enhance the thermal conductivity and to reduce the viscosity. Figure 3 represents the curve between Thermal conductivity and Temperature of normal base oil i.e. Naphthalene using the NIST- data. From the fig1 it is concluded that with the increase of temperature the thermal conductivity of normal base oil decreases. Practically this feature can be observed at the time of loading of transformer. The major requirement of oil in transformer is to avoid the excessive heat produced during overloading. So if the oil cannot stand good to provide the better thermal conductivity with respect to temperature then there is the occurrence of heat loss and the cooling of the transformer will affect. The better solution can be concluded by the addition of nano sized particle in to the normal base oil. Fig 3 shows the enhancement in thermal conductivity by the slight suspension of MgO nanoparticle. The curve shown above in fig 2 represents the 1%, 7%, 13% , 19%, 25%, and 29% volumetric nanoparticle concentration into the normal base oil i.e. below to above curve. For example at 300 K temperature thermal conductivity of base oil is found 0.13032 W/m.K when 1% MgO nanoparticle is added to the normal base oil the thermal conductivity increased to 0.134231 W/m.K, likewise for other concentrations of nanoparticle the enhancement in thermal conductivity for base oil were observed. So, now a day nanoparticles are getting more attractive to the researchers.

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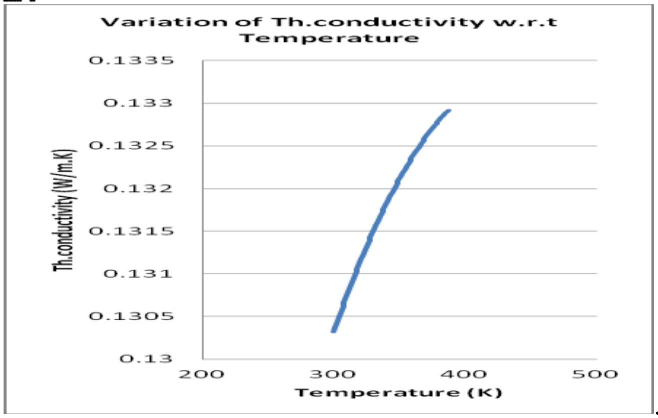

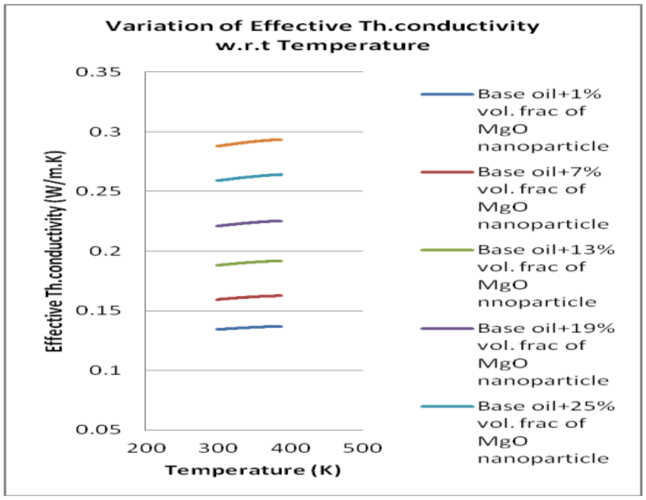

Fig 3 Comparative curve between normal oil and nanofluids

Conclusions

The main objective behind the study is improvement of transformer oils using nanofluids to overcome the several problems occurring in normal mineral oils. Minerals oils are the hydrocarbons of crude form of petroleum oil and it is highly refined with stable characteristic at high temperature with high characteristic of insulating properties.

But the normal oils have the drawbacks of moisture content, dissolved gases (sulphur), and also after a long use it reduces the heat transfer capability and fails to provide better cooling as well as long life to the transformers. To overcome the above problems a new and advanced nanosized material introducing in the field of power engineers. Nano sized material i.e. nanofluids have the greater heat transfer capability and dielectric strength. The broad area of applications of nanofluids not only stands for the transformer but also it stands for the other oil cooled machines, power plant cooling, solar devices etc. It can be concluded after viewing the several research papers that the stability of nanofluids is still a challenging task and it may overcome by the use of surfactants.

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